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Modeling and Simulation of Phase Change Material Using in Building Energy Storage

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Abstract

The purpose of this research is to design energy storage tanks using phase change material (PCM) in air conditioning system that PCM is part of the heat pump system and is connected directly to the air conditioner. From simulation and modeling methods through coding in software, parametric analysis, as well as introduction and suggestions for use a suitable PCM to store and reduce energy consumption in the building and check the performance of the heat exchanger in the latent heat storage using phase change materials is effective, are discussed. In this paper, first the thermal and refrigeration loads calculated using Carrier software and in the following, the cooling and heating process is simulated. Finally, from the phase change material in different modes used for energy storage in cooling and heating processes and is simulated in EES software. After modeling analysis with a minimum temperature of -5°C and maximum temperature 38°C considered and in different situations, the most suitable option for PCM tank mode in the heating process at the inlet temperature 35°C using 20 pipes in each row and PCM tank mode in the cooling process at the inlet temperature 10°C and selected using 22 tubes in each row.

Keywords: Simulation, Modeling, Phase Change Material, Energy Storage, Building.

1. INTRODUCTION

PCM is called phase change material. These materials are organic or inorganic compounds that have the ability to absorb and store large amounts of heat energy within themselves. The storage of thermal energy in these materials occurs during the phase change process (change of state from solid to liquid or vice versa) as shown in Figure 1.

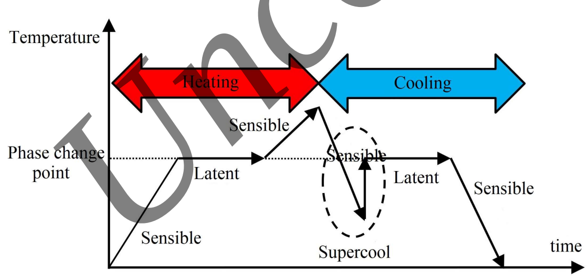

Figure 1. Temperature change during the thawing and freezing process.

In this paper, the performance of a heat exchanger that is effective in storing latent heat storage using phase change materials is investigated to solve this problem, simulation and modeling methods by coding in software, as well as parametric analysis and suggestions for using appropriate PCM to store and reduce energy consumption in the building have been discussed. Due to the use of new energy sources and the invention of new methods in order to manage and reduce energy consumption, this research is considered by experts, especially designers of mechanical facilities of the building and can be implemented in office, commercial and residential applications.

The hypotheses used in this research include the use of phase change materials for energy utilization and storage, as well as air conditioner simulation in Carrier software and system modeling and related coding in EES software and solution conditions. The issue is considered stable.

2. RESEARCH BACKGROUND

Zalba et al. [1] proposed two methods for classifying PCMs. The first method is classification based on the structure of the phase change material and the second method is classification based on the phase change temperature. In the first method, PCMs are structurally divided into materials with organic, inorganic and alloy compounds, and organic PCMs are classified into paraffin and non-paraffinic categories. In comparison of paraffin and non-paraffin PCMs, we can mention high latent heat of melting, small volume change during melting, low vapor pressure in non-corrosive melt state and relatively cheapness. Whereas the surfaces surrounded by paraffin act as a surface with a high heat flux; Therefore, the use of these paraffinic materials, due to the low thermal conductivity of PCMs, increases the efficiency of these materials. One of the most important disadvantages of this type of PCM is its incompatibility with plastic tanks and its relatively high flammability. Organic paraffins, better known as fatty acids, are the most abundant PCMs with highly variable properties. Unlike paraffins, which have similar properties, each of these materials has its own unique properties.

The problem with these materials is that they are up to 2.5 times more expensive than paraffins, and the acids are relatively corrosive. Inorganic PCMs, which are more than ordinary organic materials, are materials that do not have carbon compounds in their structure. The use of these materials in severe cooling is a phenomenon that does not have regular temperature changes. Common problems with inorganic PCMs are overcooling and temperature instability. The problem of PCM overheating should be thoroughly investigated during freezing. Regarding the innovation of this research, it can be said that a new schematic for the use of PCM system was created by the authors. The process of using the PCM system in this way has never been seen in any research that was considered in this article and the equations were simulated and solved using EES software and then analyzed and selected the appropriate mode.

3. MODELING AND SIMULATION OF THE PROBLEM

In this paper, PCM is specifically present in a heat pump system with an air conditioning unit. Therefore, the design of PCM storage space should be considered. PCM tanks should be more efficient and efficient for the air conditioning system to store energy and use it in heating and cooling. Two different climatic conditions in this system are considered for heating applications for cold winter weather conditions in the mountainous regions of Iran with a temperature of -5°C as well as hot summer conditions of Iran 38°C which is simulated Performed by EES software.

3.1. Description of the proposed system

The purpose of this paper is to analyze, study and design energy storage tanks using PCM in air conditioning system. Figure 2 is a schematic of the model proposed by the authors of this paper, which consists of a heat pump, as well as two PCM tanks (for cooling and heating) and an air conditioning unit, which are discussed for different charging and discharging modes. The heat pump adjacent to the PCM storage tank using the heat transfer fluid in the model is investigated in this paper. One of the main points of this installation method is to use electricity with low electricity cost during the night for charging and the intended time for discharge during the day is 8 hours. The energy contained in the heat pump in the PCM tanks is transferred to the air conditioning system to provide heat power. Both PCM heating and cooling tanks are used to store thermal energy with PCM. Two different types of PCM storage tanks are considered for the system under study. One of them is PCM in volume and the other is available using PCM microencapsulation. The desired space has an area of 1000 m^2. PCM tanks must store thermal energy overnight using an electric heat pump.

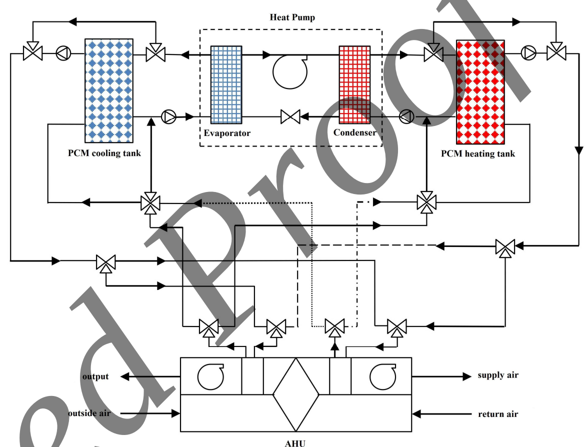

Figure 2. Schematic of the proposed model presented in the research by the authors.

The flowchart and solution method of this research are also shown in chart 1.

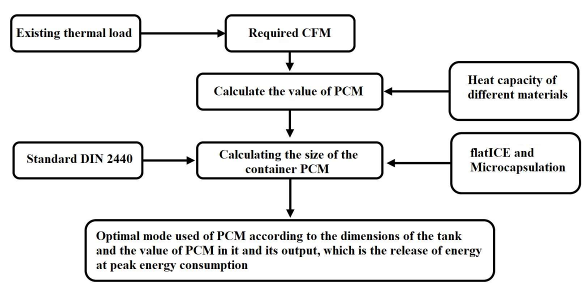

Chart 1. Flowchart Problem solving and simulation.

The value of the pendulum related to the viscosity and conductivity of the liquid is calculated from Equation 1:

$$Pr_{HTF} = C_{p,HTF} \cdot \mu_{HTF} \cdot \frac{\rho_{HTF}}{k_{HTF}} \quad (1)$$

The Nusselt number is the ratio of convective and conductive heat transfer, which in a slow flow Nusselt number is equal to 3.66, otherwise it is calculated from Equation 2:

$$Nu_{HTF} = \frac{(Re_{HTF} - 1000).Pr_{HTF} \cdot \frac{f}{2}}{1 + 12.7 \cdot \left(Pr_{HTF}{}^{2/3} - 1\right)\sqrt{\frac{f}{2}}} \quad (2)$$

3.2. PCM microencapsulation tanks

How PCM microencapsulation tanks work Heat or a heat transfer fluid flows through the cavity in the bed. In the charging mode, the hot heat transfer fluid carries energy from the source, which is distributed through the tank. Inside the capsule, it transfers heat to the PCM. In both charge and discharge modes, the difference between the mean temperature of the heat transfer fluid and the phase change temperature must be sufficient to obtain a satisfactory heat transfer rate. Advantages of PCM microencapsulation include avoiding large phase separation, increasing heat transfer, and providing a structure to support PCM [2]. In this paper, PCM microencapsulation from PCMP products [3] has been selected for study. The FlatICE 500 package measures 500mm×250mm×32mm. In this type of tank, PCM is present in FlatICE containers. Heat transfer fluid flows into the cavity between the FlatICE containers to transfer heat between the liquid and other materials.

The hydraulic diameter depends on the width of the tank and is calculated by Equation 3, where L is the width of the tank and the value is 0.013m.

$$D_h = \frac{2 \cdot L_{FlatICE} \cdot 0.013}{L_{FlatICE,tank} \cdot 0.013} \tag{3}$$

V_{PCM} is the amount of volume specified by the container, not the heat transfer fluid. Therefore, V_{HTF} is the volume of the tank for both heating and cooling modes and is calculated from Equation 4:

$$V_{FlatICE,tank} = V_{PCM} + V_{HTF} \tag{4}$$

The tanks are considered to be rectangular in shape, in which case their volume depends on three parameters:
Width $V_{FlatICE,tank}$, length $Long_{FlatICE,tank}$, and height $H_{FlatICE,tank}$ (Equation 5).

$$V_{FlatICE,tank} = L_{FlatICE,tank} \cdot Long_{FlatICE,tank} \cdot H_{FlatICE,tank} \tag{5}$$

The volume of heat transfer fluid is calculated by unit volume of virtual pipes and their total number in Equation 6.

$$V_{HTF} = V_{virtual,tube} \cdot n_{virtual,tube} \tag{6}$$

In order to determine the number of virtual tubes of the FlatICE factor, which are related to the number of PCM containers in the tank and the hydraulic diameter, equations 7 and 8 have been used.

$$n_{virtual,tube} = n_{FlatICE} \cdot f_{FlatICE} \tag{7}$$

$$V_{virtual,tube} = \frac{1}{4} \cdot \pi \cdot {D_h}^2 \cdot Long_{FlatICE,tank} \tag{8}$$

In macroencapsulated PCM tanks, the heat transfer between the PCM and the heat transfer fluid calculated using the log is the temperature difference method. Therefore, to apply this method, the thermal resistance obtained from Equations 9 and 10 is calculated:

$$R_{HTF} = \frac{1}{h_{HTF}} \tag{9}$$

$$R_{PCM} = \frac{0.016}{K_{PCM}} \tag{10}$$

The total heat transfer surface, taking into account the number of FlatICE containers used in the tank, was obtained from Equations 11 and 12:

$$A_{FlatICE} = L_{FlatICE} \cdot Long_{FlatICE} \cdot 2 \tag{11}$$

$$A_{total,FlatICE,tank} = A_{FlatICE} \cdot n_{FlatICE} \tag{12}$$

4. ANALYSIS OF FINDINGS

4.1. Volume of PCM heating and cooling tanks

After determining the governing equations in this research, it is stated separately for each part as follows.

4.1.1. Heating tank

The desired heating tank was performed using a PCM with a phase change temperature of 28°C in order to calculate the dimensions of the tank. According to the dimensions of the tank described, the above parameters were calculated for charging operations. In this case, the inlet temperature for PCM charging must be high enough. Therefore, the inlet temperature is assumed to be 35°C.

4.1.2. Cooling tank

This cooling tank was performed using a PCM with a phase change temperature of 0°C to calculate the dimensions of the tank and the parametric study of pipe diameters in different sizes and according to the results obtained and according to the specifications of the cooling coil. And heat loss, the choice of tank size according to the heat transfer of the outlet temperature is considered. Therefore, according to the specifications of its cooling coil, the diameter is 26.9 mm for pipes. During the charging process, the temperature of the heat transfer fluid must be sufficiently reduced. A mixture of water and liquid propylene glycol ($C_3H_8O_2$) was selected in this modeling. Therefore, the inlet temperatures with 0°C and -5°C are considered.

4.2. Macroencapsulated PCM tanks

4.2.1. Heating tank

The heating tank with coil consists of an air conditioner. The PCM temperature is set at 38°C to be useful enough to heat the room. The tank parameters are shown in Table 1.

Table 1. Fixed parameters obtained for macroencapsulated PCM heating tank.

Parameter	Value
The heat transfer	108 kW
Stored energy	864 kWh
PCM mass	21451 kg
FlatICE Volume	0.0038 m^3

Discharge time	8 h
PCM density	1505 kg/m^3
PCM latent heat capacity	145 kJ/kg
Tank volume (V_{tank})	21.21 m^3
V_{PCM} / V_{tank}	%67.56
PCM temperature	33ºC
Hydraulic diameter	0.02587 m
Total area exchange	937.7 m^2
Number of PCM containers	3751
Width	3 m

4.2.2. Cooling tank

This cooling tank was performed using a PCM with phase change temperature of 0°C in order to calculate the dimensions of the tank and study the actual dimensions of the cooling tank in Table 2 it has been shown:

Table 2. Fixed parameters obtained for macroencapsulated PCM cooling tank.

Parameter	Value
The heat transfer	76.87 kW
Stored energy	615 kWh
PCM mass	6668 kg
FlatICE Volume	0.0038 m^3
Discharge time	8 h
PCM density	1000 kg/m^3
PCM latent heat capacity	332 kJ/kg
Tank volume (V_{tank})	9.87 m^3
V_{PCM} / V_{tank}	%67.56
PCM temperature	0ºC
Hydraulic diameter	0.02583 m
Total area exchange	438.7 m^2
Number of PCM containers	1755
Width	2 m

5. CONCLUSION

In this paper, we design PCM tanks for storing thermal energy for use in air conditioning systems, according to previous research, which was in line with the numerical analysis of PCM systems and was done in this regard. This research is different from other researches in terms of determining a new schematic for using PCM system, which is simulated and solved equations using EES software. Also, the purpose of this article is that the designed tanks should improve the energy efficiency of the system and the PCM should store thermal energy and use it for heating and cooling. According to the studies performed and the observation of the simulation results by the software, the following results have been obtained:

In the analyzes performed by the codes written in the simulation, eight different modes of charge in the heating and cooling processes and discharge in the heating and cooling processes in PCM and microencapsulation tanks have been investigated. Considering the different conditions of the PCM tank in the heating process and the results, it can be concluded that the PCM tank in the heating process with an input heat of 35°C, if using 20 pipes in each row with other parameters related to It has the highest productivity and maximum efficiency. It can also be concluded that the PCM tank has the highest efficiency and maximum efficiency in the cooling process with an inlet heat of 10°C and in case of using 22 pipes in each row along with other related parameters.

In addition, to continue the research, it is suggested to use a heat pump and air conditioning system with higher efficiency and lower cost, and by reducing the size of PCM tanks, which is one of the effective factors in the implementation, an effective step can be taken. It was important in improving this.

6. REFERENCES

[1] B. Zalba, B. Sanchez-valverde, J. Marin, An experimental study of thermal energy storage with phase change materials by design of experiments, *Journal of Applied Statistics*, Vol. 32, pp. 321-332, 2005.

[2] Y. Fanga, Z. G. Qua, J. F. Zhanga, H. T. Xub, G. L. Qi, Simultaneous charging and discharging performance for a latent thermal energy storage system with a microencapsulated phase change material, *Applied Energy*, Vol. 275, 115353, 2020.

[3] Zhang Tao, Xiao Chen, Mu Yang, Xiaoliang Xu, Yan Sun, Yaqiong Li, Jingjing Wang, Ge Wang, Three-dimensional rGO@sponge framework/paraffin wax composite shape-stabilized phase change materials for solar-thermal energy conversion and storage, *Solar Energy Materials and Solar Cells*, Vol. 215, 110600, 2020.